# CRITICISMS AND DISCUSSIONS.

## AUGUSTUS WALLER'S EXPERIMENTS IN ELECTRO-PHYSIOLOGY.

[On his last trip to Europe during the Parisian exhibition, the editor visited in London Prof. Augustus Waller, whose work on electrophysiology had attracted his attention in various ways. Prof. Augustus Waller, son of the famous physiologist, possesses a pleasant home in a northern suburb of London to which a comfortable and spacious laboratory, originally built by a former owner of the house as an artist's studio, is attached. It is furnished with all necessary apparatus and wired according to the needs of the experiments, with a suspended table counterpoised from the ceiling, easily removed when no longer needed. Here the professor spends his leisure hours in the company of his congenial wife, the most faithful helpmate in his scientific labors. Professor Waller's investigations are of great importance and by no means limited to his specialty, for he takes also a deep interest in the logical principles of scientific enquiry and has promised to furnish *The Monist* a contribution on that intricate problem.

For the facts stated in the present communication of Augustus Waller's work in electrophysiology the editor is indebted not only to the professor himself but also to his wife who has been most obliging in furnishing the necessary data.—EDITOR.]

"Living nervous matter—all living matter indeed—is 'excitable' and responds to its 'call-from-without' by some form of movement—chemical movement, mechanical movement, electrical movement. An isolated muscle gives sign of life by contracting when stimulated, and we are able by more or less refined methods to show that such contraction is accompanied by physico-chemical changes—production of acid, evolution of carbon-dioxide, rise of temperature, electromotive action. An ordinary nerve, normally connected with its terminal organs, gives sign of life by means of muscle, which by direct or reflex path is set in motion when the nerve-trunk is stimulated. But such nerve separated from its natural termini, isolated from the rest of the organism, gives no sign of life when excited, either in the shape of chemical or of thermic changes, and it is only by means of an electrical change that we can ascertain whether or no it is alive. The eye—the retina—is known to

us as a living organ in our own persons when we see an external object. By various devices of the laboratory we measure quantities of stimulant light and differences of excited sensation. The isolated organ—an entire eyeball, or its isolated retina—is best known to be alive or not by means of its electrical response or silence when it is put to the question by its natural stimulus, light. In these three cases named, the most general and most delicate sign of life is the electrical response."[1]

These words give the keynote to Dr. Waller's work in electrophysiology during the last five years. The electrical response to any sort of excitation gives a remarkably precise indication of the state of any living tissue, e. g., in muscle the decreasing and fatigue curve of mechanical contraction is shown to follow closely parallel with the curve of its electrical response.

Dr. Waller has decided a question of psychological interest by means of the electrical response of the eyeball. It is found generally that equal increments of stimulation produce diminishing increments of sensation (Weber-Fechner curve), and he asks the question : Is this disproportion of physiological or of psychological origin? He divides the process of sensation into three parts : (1) the outside phenomenon which causes it, (2) the internal stimulus, e. g., the change provoked by it in the nervous system (in physiological ground), (3) the sensation itself (in psychological ground), and then asks: does the disproportion take place in physiological or in psychological ground ? To solve this problem a study is made of the frog's eyeball in which the effect of a known standard of light can be measured on a galvanometer by the electrical change it causes in the eyeball. The magnitude of stimulation was in this case varied by altering the distance from the retina of a standard candle and recording by photograph, the galvanometric deflexion. The curve obtained on the record resembled the Weber-Fechner curve so that, taking the eyeball as the intermediate physiological ground between the external stimulating phenomena and the psychological ground of the sensation itself—the disproportion is in physiological ground, not in psychological ground.

The electrical condition of substance is most conveniently studied by means of the galvanometer which gives a measure of electromotive force, and for all these investigations Dr. Waller has contrived a simple arrangement of instruments easily modified according to the subject studied. The centre of all the apparatus is a keyboard made up of a straight piece of brass on an ebony stand ; to this piece of brass are fixed pairs of brass terminals and between each pair the brass is broken and a brass plug or key inserted. By means of this keyboard the electrical circuit can be controlled ; one pair of terminals is attached by wires with a demonstrating galvanometer, another is connected with the animal or vegetable substance to be studied, another is attached to the exciting coil or battery or condenser, a fourth

[1] "On the excitability of nervous matter, with especial reference to the retina." *Brain*, Part I. 1900.

is connected with a resistance box for measuring the electromotive force of the subject studied, a fifth pair may be attached to a recording galvanometer and by means of the keys any of these objects may be brought into the circuit or shut out from it. The recording galvanometer is kept in a dark room, and the movements of its magnet are photographed, the light passes through a fine vertical slit in a box containing a lamp and is focussed on the mirror of the magnet and reflected on to a horizontal slit in a box containing the photographic plate; the dark slide containing the photographic plate is attached to a clock on top of the box which is arranged to allow the plate to descend quickly or slowly behind the horizontal slit. By this method the movements of the galvanometer can be accurately recorded by photography.

Nerve is now admitted to be practically an inexhaustible tissue. Waller showed that its apparent exhaustion in a nerve-muscle preparation is due to the breakdown of the motor-end plate which is the link between nerve and muscle; but a strand of nerve is practically inexhaustible and a series of electrical stimuli will evoke an even series of responses, first noticed and called by DuBois-Reymond, negative variations because negative to the normal current of injury of the nerve; positive variations are also evoked and Waller points out that it is this extreme negative and positive effect, a breaking down and building up process which causes the inexhaustibility of nerve; on account of its stability he chose nerve as a convenient tissue to study under a variety of chemical conditions, and he adopted the following method.

The sciatic nerve of a frog is dissected out, cut at its muscle end, and left attached to a piece of spinal column by which it can be lifted to avoid injuring the nerve. It is placed on four electrodes in a moist chamber having an inlet and outlet for the passage of gases. Two of the electrodes at the distal end of the nerve are unpolarisable, leading off to a galvanometer, the other two placed nearer to the spinal end of the nerve are exciting electrodes from a Berne induction coil. The nerve is excited once a minute and its electrical response is observed on the galvanometer. At each excitation the galvanometer spot (image of a vertical slit in front of a lamp reflected on a scale by the mirror on the swinging magnet of the galvanometer) swings steadily and its movement is photographically recorded on a sensitive plate which descends by clockwork behind a horizontal slit in a dark box. Taking a strand of nerve as representative of living matter, the effects of chloroform, ether, nitrous oxide, and other anæsthetics were tested on it and found to correspond with their known effects on man and animals. The effect of chloroform is shown by driving air for one minute into the nerve chamber through two wash bottles, the first containing chloroform and the second water; the electrical response is finally abolished. The effect of ether was tried in the same way with the result that the response was temporarily abolished. By means of this method, comparison was made between chloroform and other chloromethanes, nitrous oxide and carbonic acid, and the effect of chloroform at different strengths. Chloroform

was carefully compared with ether and found to be seven times more powerful, By diluting chloroform, the effect of different strengths of the drug was observed and the reaction was found to be most exact and delicate. One per cent. vapor caused partial abolition of the negative variation with complete recovery, two per cent. caused greater abolition with recovery, three per cent. and four per cent. gave still greater effect while five per cent. vapor caused profound anæsthesia with bad recovery, and strengths above this caused death of the nerve. These results correspond remarkably with what has been found to be a safe quantity of chloroform to use in anæsthetising the human subject. This part of Dr. Waller's work has an important bearing on a matter of general public interest, "deaths from chloroform."

Carbonic acid gas gave most interesting results: it was found that the negative variation was diminished or altogether stopped during the passage of the gas, afterwards it was greatly augmented. If expired air or dilute carbonic acid gas, was passed over the nerve the responses to electrical excitation were augmented without any primary diminution. These effects of carbonic acid gas were peculiarly interesting because they led to the expectation of finding evidence of chemical action which has never been observed before in nerve although chemical and thermic changes have been observed in muscle. Any activity in living tissue is accompanied with the formation and discharge of carbonic acid; a small amount of carbonic acid—such as is contained e. g. in expired air—causes a marked augmentation of the negative variation. An isolated nerve might act thus as an indicator of the presence of carbonic acid.

Supposing that carbonic acid was formed within the nerve itself during its excitation, one would expect to find that the negative variation was augmented at first and then gradually diminished as the carbonic acid became dissipated. On this hypothesis Dr. Waller forecast in a diagram on the black-board the kind of tracing that he expected to obtain in the photographic record of the actual experiment. The diagram represented the normal series of equal steady responses to electrical excitation lasting one eighth of a minute at one minute interval, then a descending line during five minutes tetanus and afterwards the series of one minute stimuli augmented in value and then diminishing The experiment was started and recorded and the development of the photographic record awaited with intense interest. The result was exactly as expected: the photograph came out similar to the diagram and showed evidence of chemical action in nerve, an evolution of carbonic acid which acted in the substance of the nerve just as slight amounts of the gas act on it when the nerve is lying in an atmosphere of dilute carbonic acid.

The record of a series of responses to stimuli in nerve nearly always shows a staircase effect, i. e., each response slightly exceeds its predecessor; this is also due to the stimulating effect of a slight amount of carbonic acid produced at each electrical stimulus. Carbonic acid has an anæsthetic effect on the normal beat of a frog's heart.

Dr. Waller's method has also yielded valuable results in showing the potency of various drugs and determining what part of a salt is the active factor; by what group of atoms it acts; as for instance in comparing the potassium and sodium salts and the chloride, bromide and iodide of potassium, potassium is the active element, not the chloride or bromide and a potassium salt is far more powerful than a sodium salt. There is a great similarity between the action of aconitine and acetic acid pointing to the probability that aconitine acts by virtue of an acetyl group.

From observing the effects of anæsthetics upon animal tissue Dr. Waller proceeded to consider their effect on vegetable protoplasm, and in conjunction with Professor Farmer he compared the influence of chloroform, ether and carbonic acid simultaneously on the mobility of nerve judged by its negative variation, while the movement in vegetable protoplasm was measured by the rate of circulation of the chlorophyll bodies. Elodea and chara were chosen for this purpose because of their simple structure; in their cells the chlorophyll bodies circulate round in a processional manner and the rate of movement can be measured under the microscope by counting the number of bodies passing per minute under a cobweb placed in the eye-piece. Carbonic acid gas passed through the little chamber containing the plant, and through the nerve chamber, caused stoppage of the circulation and stoppage of the negative variation; on aerating the two chambers the chlorophyll corpuscles began to move fitfully, then more rapidly than usual and afterwards resumed their normal rate; simultaneously the nerve gave increased negative variations and afterwards a normal series. Ether vapor arrested the circulation temporarily and chloroform abolished movement permanently unless a very weak vapor of two per cent. in air were used when a temporary arrest was caused, thus corresponding remarkably with the strength which Dr. Waller has shown to be safe in the case of the human subject.

In considering the immense influence of light in causing chemical and electrical changes, Dr. Waller tried the effect of light on green leaves to see if light causes any perceptible electrical change and he found such to be the case. The experiment is a most elegant one: the leaf of an iris, laid on a glass plate and partly shaded with black paper, was enclosed in a dark box fitted with a small shutter that can be opened to allow light (either the arc light or sunlight) to fall upon the uncovered part of the leaf on which unpolarisable electrodes are placed leading to a galvanometer, a deflexion of the galvanometer magnet occurs beginning and ending sharply with the beginning and end of illumination and amounting sometimes to ·02 of a volt.

During observations on the frog's eyeball Dr. Waller noticed that as an after-effect of any excitation, induction shock or condenser discharge, an electrical current was invariably obtained from the fundus to cornea. This current he called the blaze current; it does not occur in a dead eyeball and he subsequently found that blaze currents are characteristic of living matter and can be utilised as a sign

of vitality. After testing various tissues, animal and vegetable, Dr. Waller made a closer study of blaze currents on beans. On uninjured beans the blaze current is in the same direction as the exciting current. The bean to be tested is placed between two unpolarisable electrodes; after compensating any accidental current which the bean may exhibit so that on plugging and unplugging the galvanometer no movement of the zero is visible, the galvanometer is plugged, the bean is submitted to an induction current or a condenser discharge for a short period, five seconds, the galvanometer is then unplugged and the after-effect observed. On an uninjured bean the after-effect or blaze is invariably in the same direction as the excitation. It lasts a considerable time, five to fifteen minutes and can be described as being a local explosive change in the living matter. In an injured bean the blaze occurs only in the direction from uninjured to injured surface to either direction of excitation but is distinguished from polarisation counter current by its much greater magnitude and duration. A boiled bean gives no blaze current in either direction but only small polarisation counter currents.

Anæsthetics were tested on the blaze currents. To obtain temporary suppression of the blaze currents it was found necessary to choose a sufficient but not too strong exciting current and to anæsthetise rather by ether than by chloroform. Comparison was made between fresh seeds and the same seeds killed by boiling. Fresh seeds giving blaze currents of 01 to 10 of a volt give no blaze currents after boiling but only polarisation counter currents of 0005 to 0020 of a volt. Peas, beans, cherry-kernels, plums and peaches were tested in this way.

A series of experiments were made on beans of certificated years in order to show the deterioration of seeds with age. Beans were obtained dating for ten years back and were compared by the blaze test and the germination test, the proceeding was as follows: the dried beans are soaked in water for twelve hours, then placed in an incubator; the next day each bean was peeled and its radicle carefully broken off and placed between unpolarisable clay electrodes—a current of injury is observed from the broken base to the apex and a blaze current from apex to base in response to both directions of excitation. By testing the radicles prepared in this way, more uniform results were obtained than by taking the entire bean with possible unknown local bruises.

In comparing ten beans of 1899 with ten beans of 1860 the average blaze and germination test of the 1860 gave no per cent. whereas the average blaze of 1899 gave ·037 of a volt and the germination was one hundred per cent.

An interesting comparison was made between the blaze current of beans taken for five years from 1895 to 1899. The average blaze of the 1895 beans was ·0014 of a volt; of 1896, ·0036 of a volt; of 1897, 0043 of a volt; of 1988, ·0052 of a volt; and of 1899, ·0170; showing how the vitality and consequent germinating power diminish with the age of the seed.

Series of germinations were carried out parallel with the blaze tests and it was found in every instance that those which gave no blaze also failed to germinate.